GSI experiment and WDM diagnostics (PAC Q5)

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for the HIFS-VNL

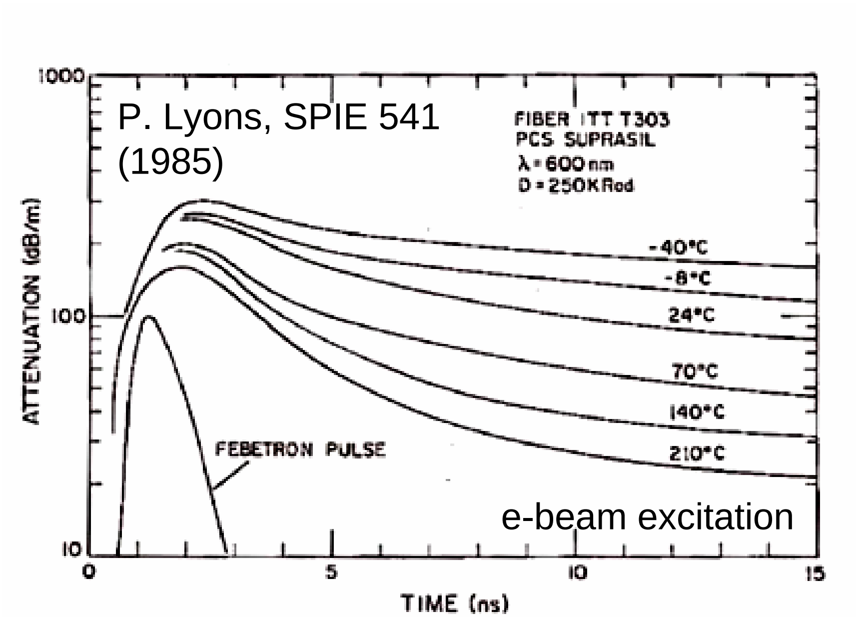
8th VNL-PAC, LBNL   Feb. 22, 2007

Overview

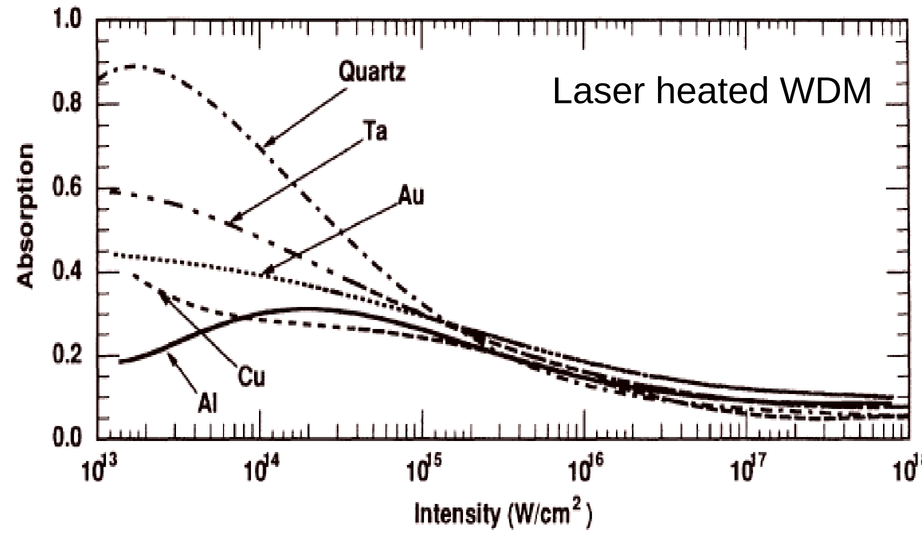
- Initial experiments:
  - Transient darkening experiment at LBNL
  - Porous target WDM experiment at GSI

- Diagnostics, including prototype target chamber

First experiment: Check WDM atomic models using transient darkening of quartz at low temperature.



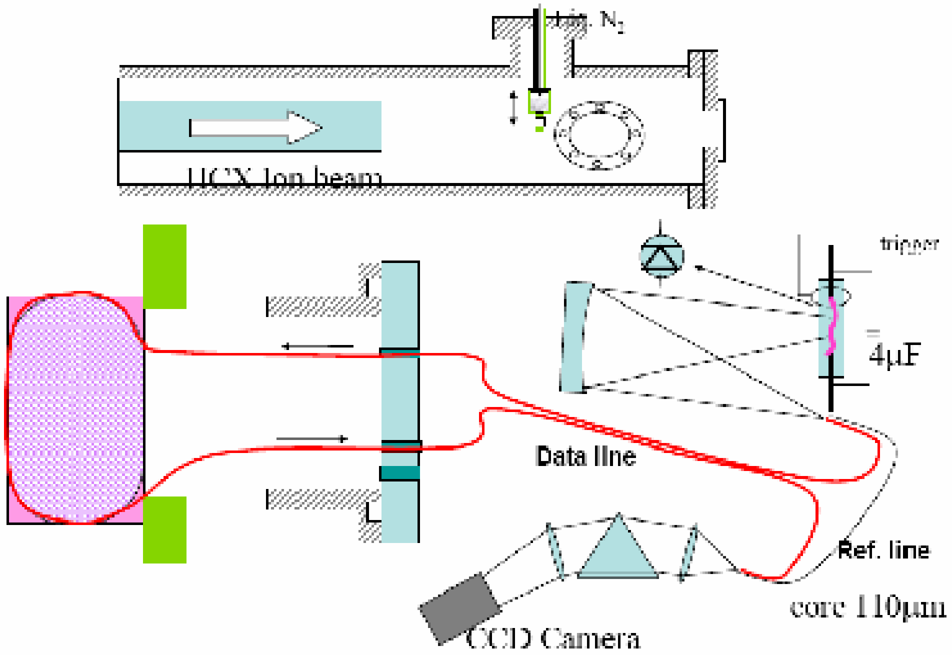
D.F. Price, et.al., PRL 75, 252 (1995)

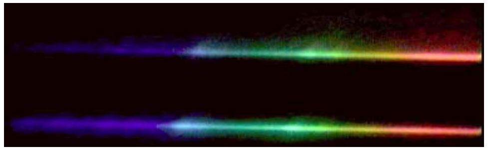


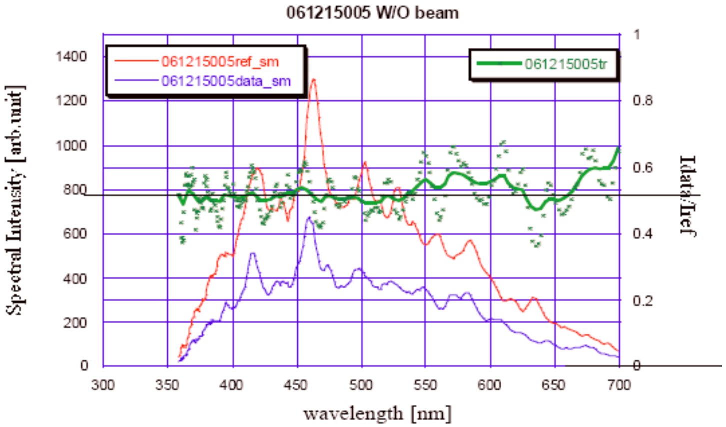
In quartz, electrons excited from 2s, 2p (ground state) to 3s leave holes in ground state to absorb photons in both cases. Measure decay rate of excited electrons by studying decay of absorption and emission rates.

Significance: interpret WDM data, possible temperature measurement, fast switching of optical properties

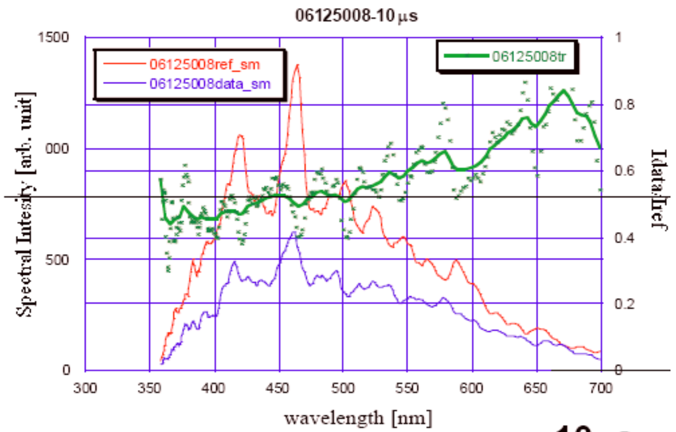
Initial transient darkening experiments in quartz fiber (with H. Yoneda, U. of Electro-communications, Tokyo).







No beam

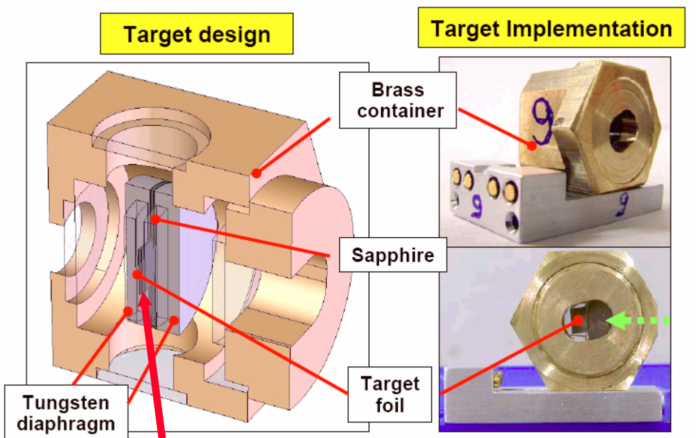


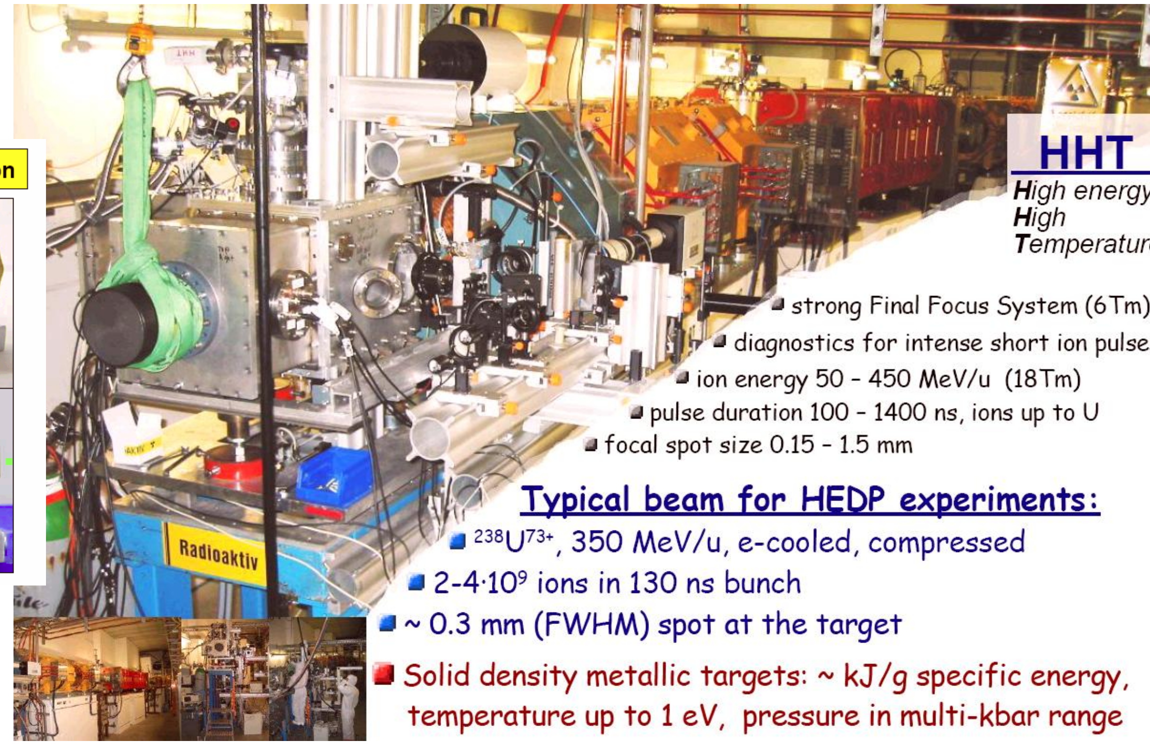
10μs

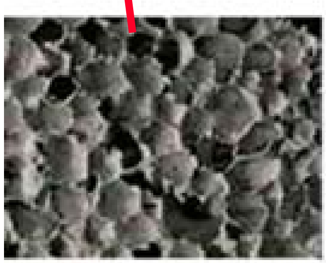
Optical transmission experiment: look for difference in fiber transmission with and without beam.

Modeling of effect of ion beam on optical fiber transmission is going on.

Porous target experiment Dec. 2006 at GSI HHT target station (with GSI Plasma Physics group; IPCP Chernogolovka; ITEP Moscow).

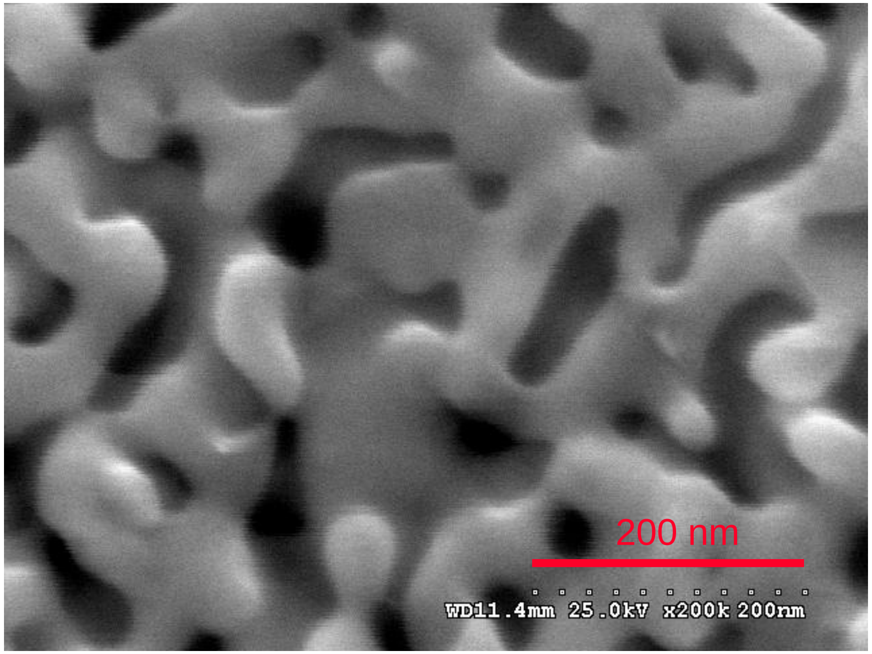


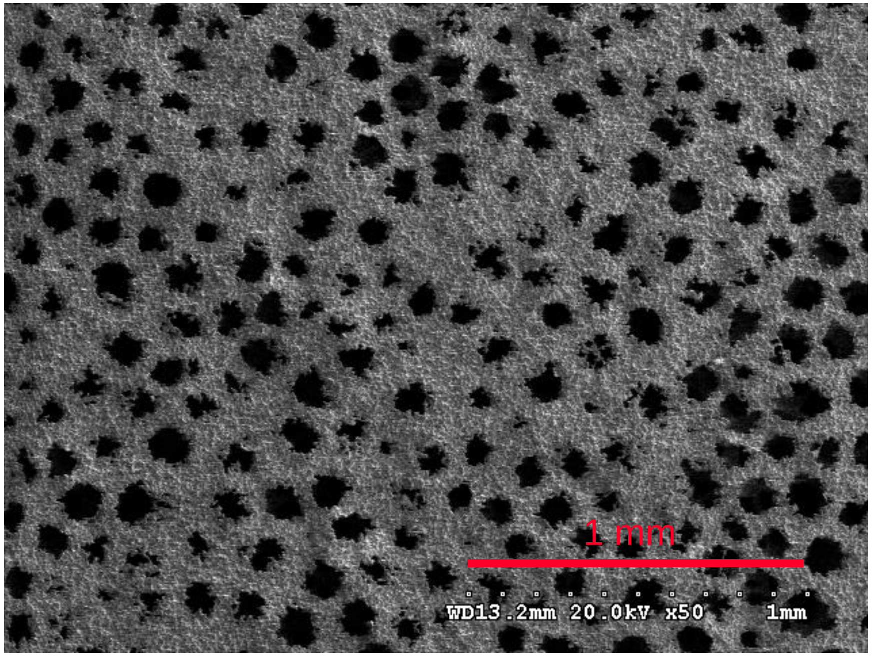




- Replace target foil with porous material.
- Study effect of pore size on target behavior using existing diagnostics.
- Sample targets: LLNL (Au, 50 nm), Mitsubishi (Cu, 50 micron).

Porous targets prepared for testing and comparison with solid targets in GSI beam.



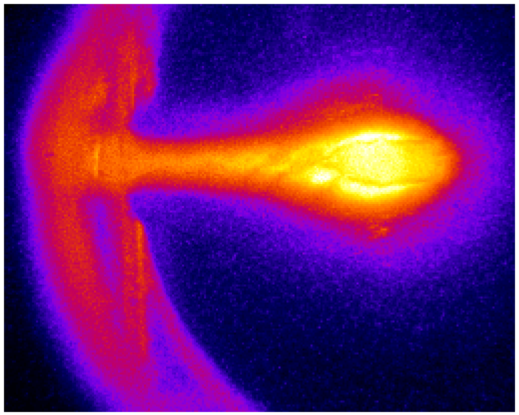


Porous gold target, 35% solid density, 50-nm pore size (Alex Hamza, LLNL)

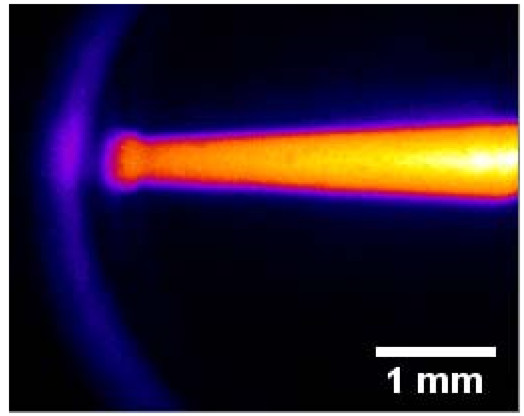
Porous copper target, ~25% solid density, 50-micron pore size (Mitsubishi)

Data analysis from GSI experiments is underway.

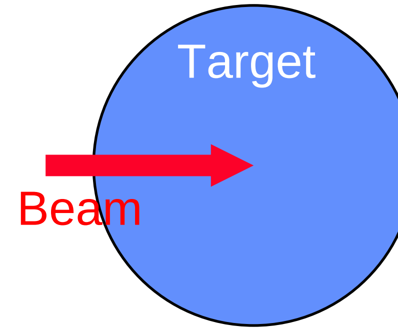
- Gold targets heated to about 6000 K (T-boil = 2435 K). Solid and porous gold targets show similar behavior (temp, 1.4 km/s expansion).



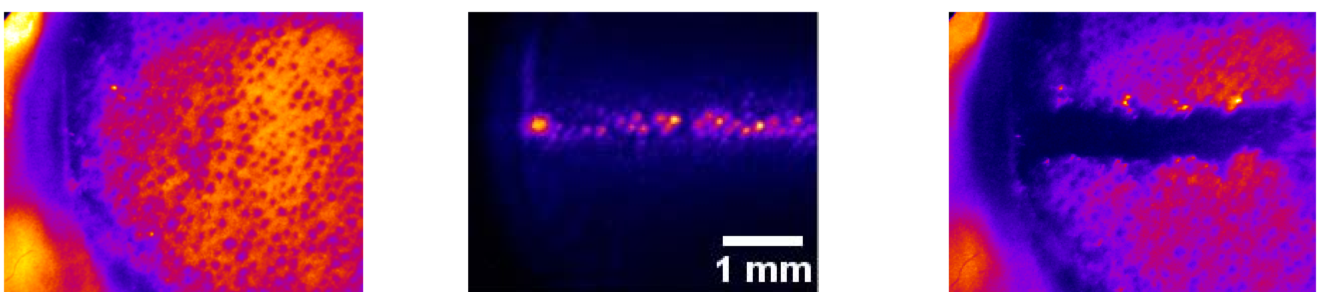
solid gold (note Bragg peak)



Porous gold

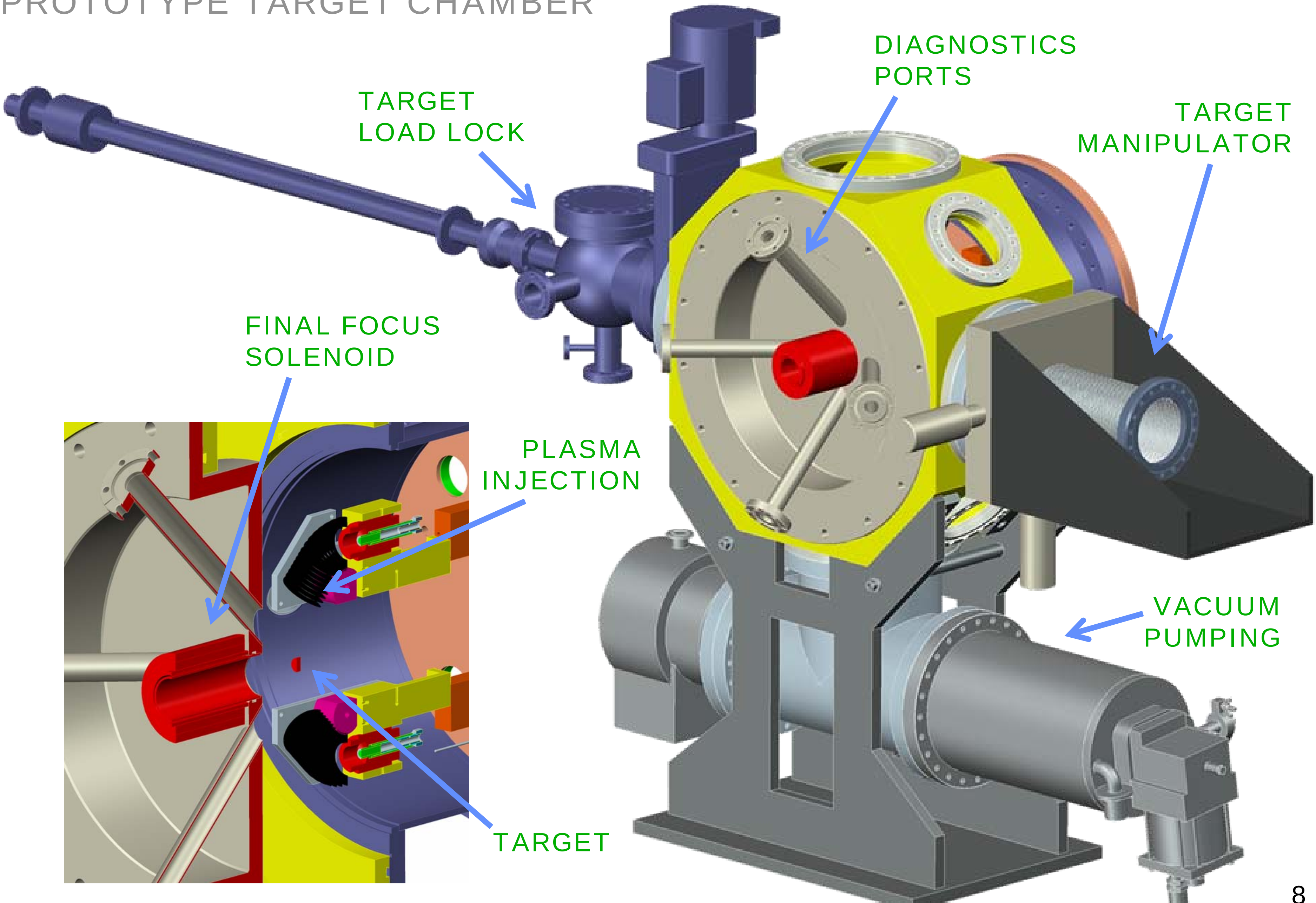


- Copper targets heated to about 3000 K (T-boil = 3200 K). Porous copper broke up into droplets.



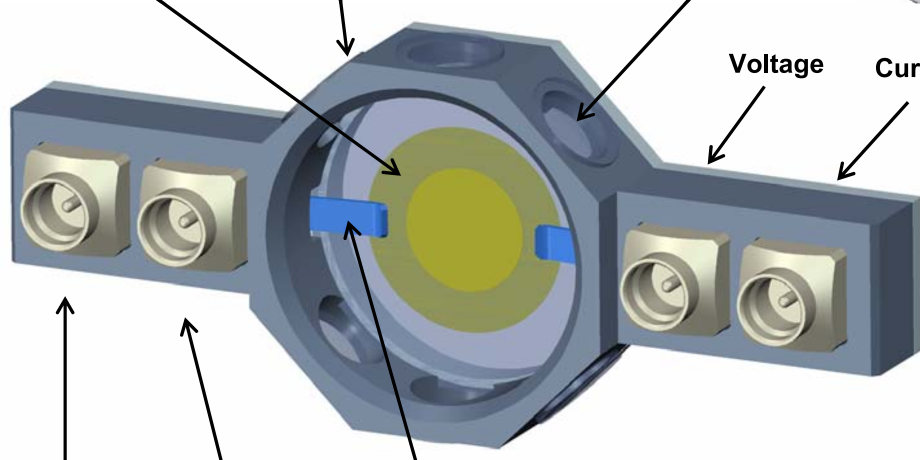
Porous copper – before, during, after beam pulse

WARM DENSE MATTER EXPERIMENTS
PROTOTYPE TARGET CHAMBER

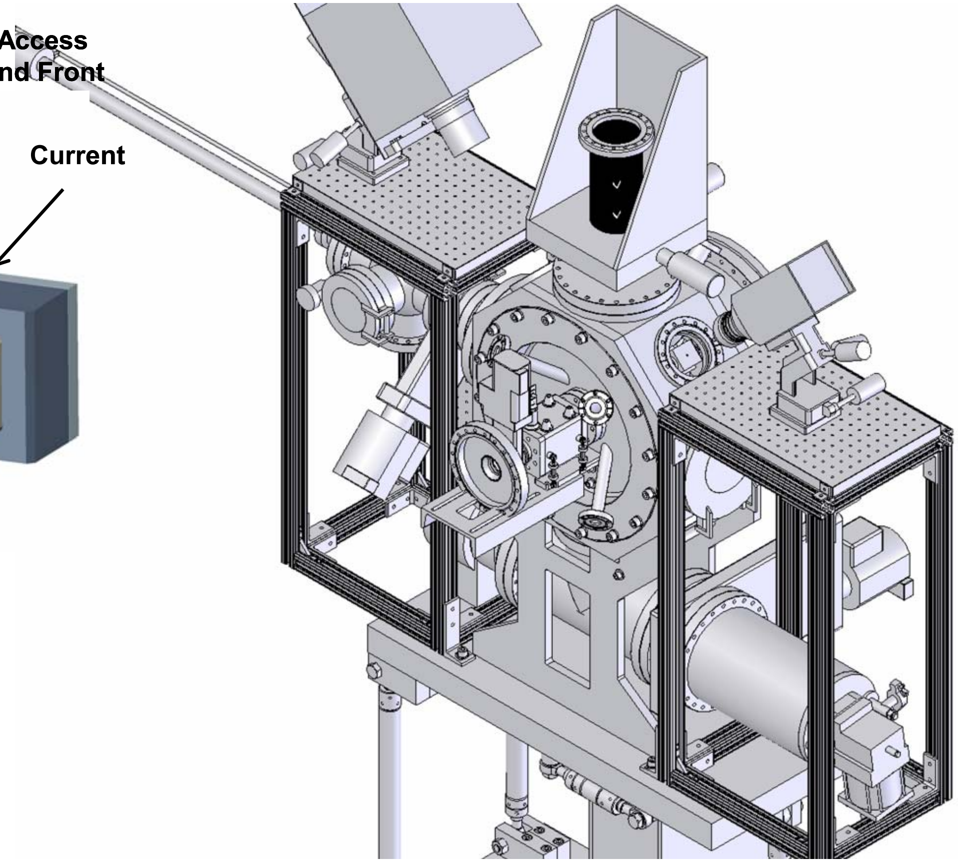


PROTOTYPE TARGET MODULE

(Size: 5.66 cm wide, 2.29 cm high)



SAMPLE DIAGNOSTICS LAYOUT



WDM physics-related beam diagnostics

- Beam spot at target
  - Fast scintillator – *Al_2O_3 scintillator in use*
  - Optical emission from hole plate/gas cloud: *self-healing, capability for better speed than solid scintillator*
  - Fast Faraday cup – *upgrade existing diagnostic*

- Downstream of thin foil target
  - Beam scattering

    Scintillator - *existing*

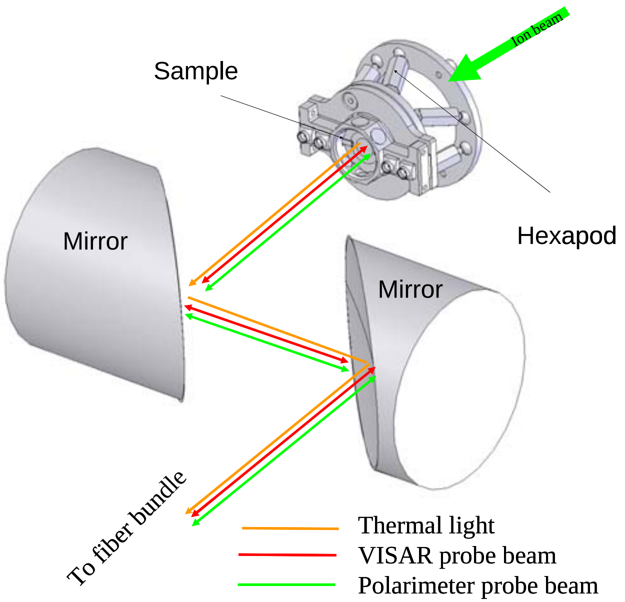
  - Beam energy/charge state

    Time of flight - *existing*

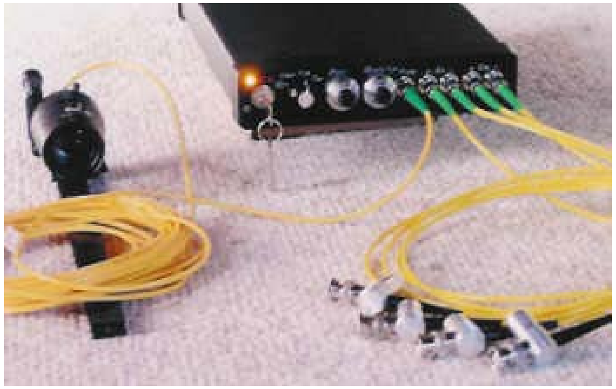
    Electrostatic energy analyzer - *existing*

Target diagnostics - 1

- **Fast optical pyrometer**
  - **Similar to GSI pyrometer, improved for faster response (~1 ns) and greater sensitivity**
  - **Temperature accuracy 5% for T>1000 K**
  - **Position resolution about 400 micron**
  - ***Parts are being ordered – to be assembled in FY07***

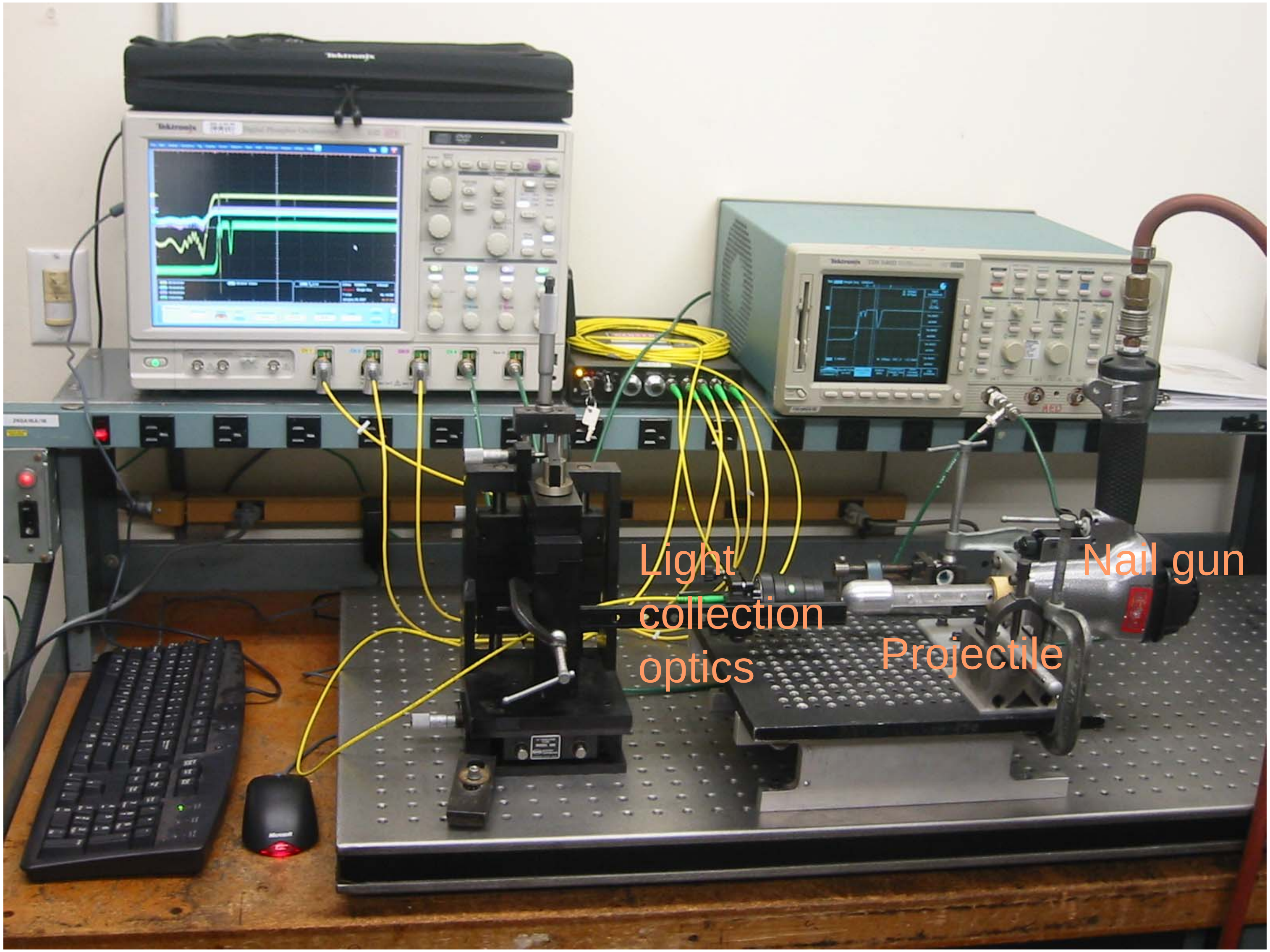


- **Fiber-coupled VISAR system – *now under test***
  - **Martin Froescher & Associates**
  - **Sub-ns resolution**
  - **1% accuracy**



- **Hamamatsu visible streak camera with image intensifier**
  - **Sub-ns resolution**
  - ***arrived Feb. 2007***

Diagnostic development and testing: VISAR



Target diagnostics - 2

- Princeton Instruments PI-MAX cameras (*2 on hand*) for single frame images of target – 16 bits, 512 x 512, 1 ns and 10 ns resolution.

- Electrical conductivity
  - initial test to be based on electrical transmission line circuit
  - conductivity may switch between insulator ←→ conductor

- Diagnostics to be developed include
  - Laser optical transmission/reflection/polarimetry
  - X-ray diagnostics

- New post-doc Pavel Ni is former GSI graduate student

- We are exploring opportunities for collaboration on improved beam profile measurements with GSI

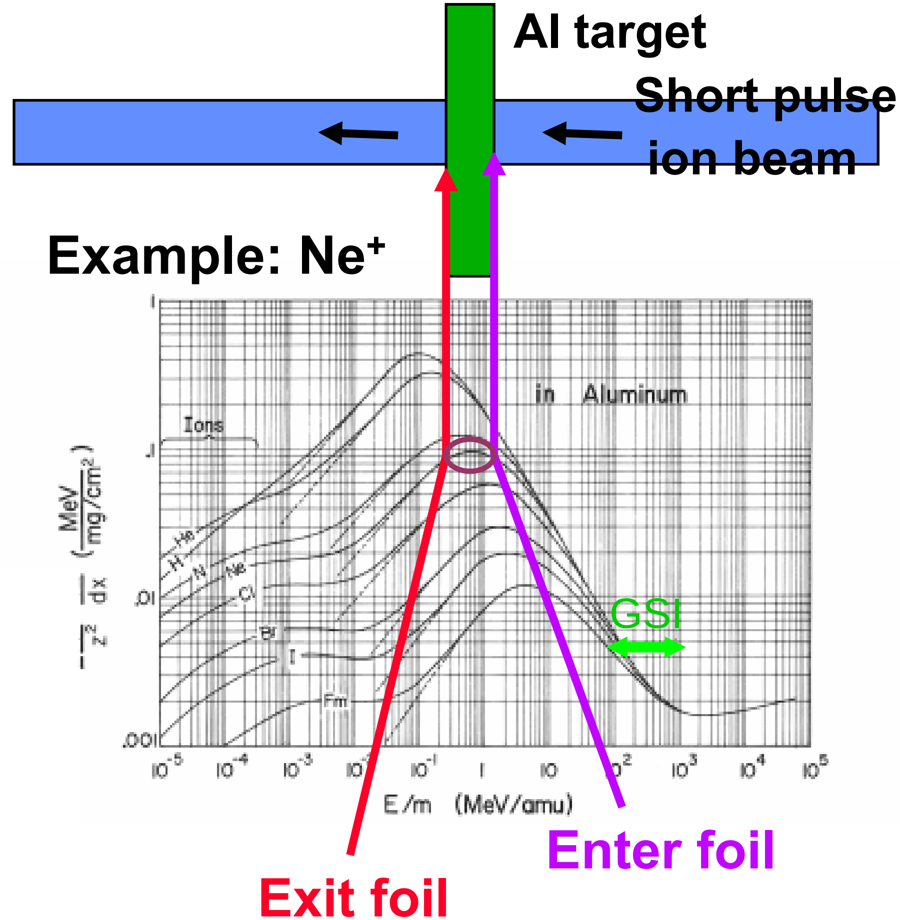
Accuracy and suitability of WDM diagnostics

- Diagnostics are designed to meet general requirements on resolution: <1 mm position and spot size, <1 ns time scale.
- Beam jitter and reproducibility will have to be characterized and optimized.
- Optical diagnostics view surface of (non-transparent) target.

Backup Slides

Ion beams provide an excellent tool to generate homogeneous, volumetric warm density matter.

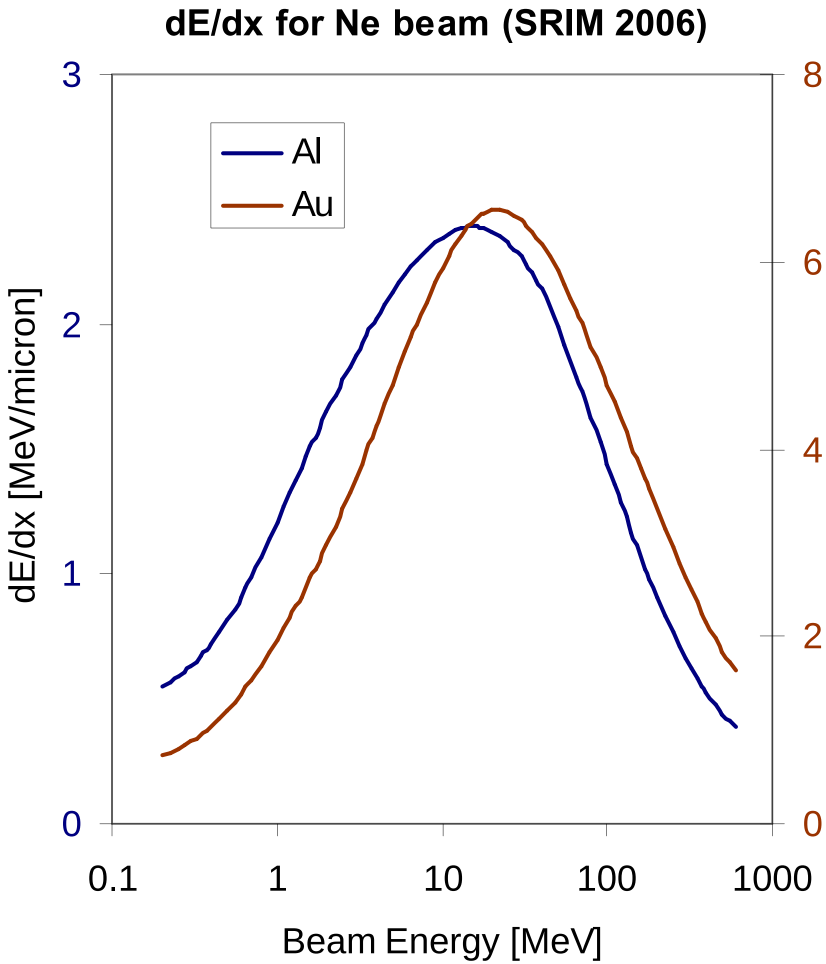
- Warm dense matter (WDM)
  - T ~ 0.1 to 10 eV
  - ρ ~ 0.01 -1 * solid density
- Techniques for generating WDM
  - High power lasers
  - Shock waves
  - Pulsed power (e.g. exploding wire)
  - Intense ion beams
- Some advantages of intense ion beams
  - Volumetric heating: uniform physical conditions
  - Any target material
  - High rep. rate
  - Benign environment



L. Grisham, Phys. Plasmas 11 (2004) 5727.

Beam energy at Bragg peak overlaps for various materials.

- dE/dx (Ne) is within 10% of maximum:
  - 5-40 MeV for Al
  - 10-50 MeV for Au
- Peak dE/dx is
  - 2.4 MeV/micron in Al
  - 6.5 MeV/micron in Au
- Energy deposition and target heating are stronger with a heavy target.
  - For a given incident beam (20 MeV Ne^{+}), instantaneous temperature rise in gold is greater than in aluminum by factor ~2.5
  - Al: 10°C/(nC/cm^2)
  - Au: 25°C/(nC/cm^2)



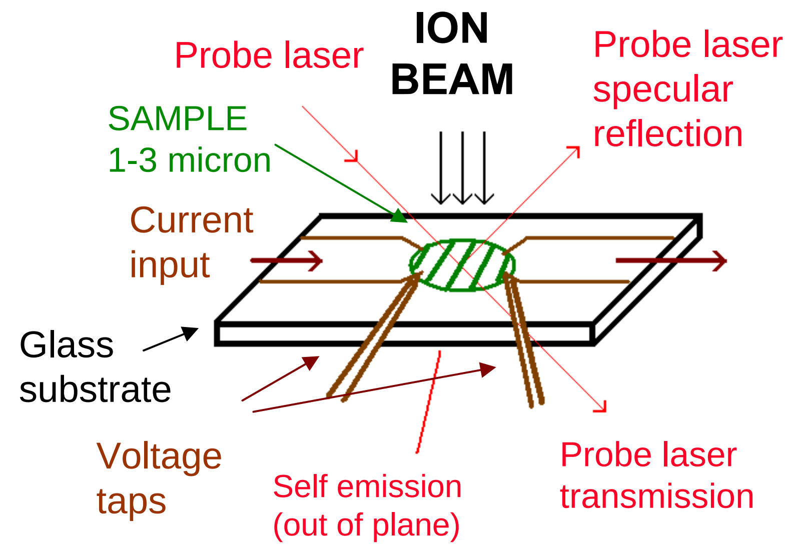
Near-term experiments provide opportunity to gain experience with diagnostics on WDM targets.

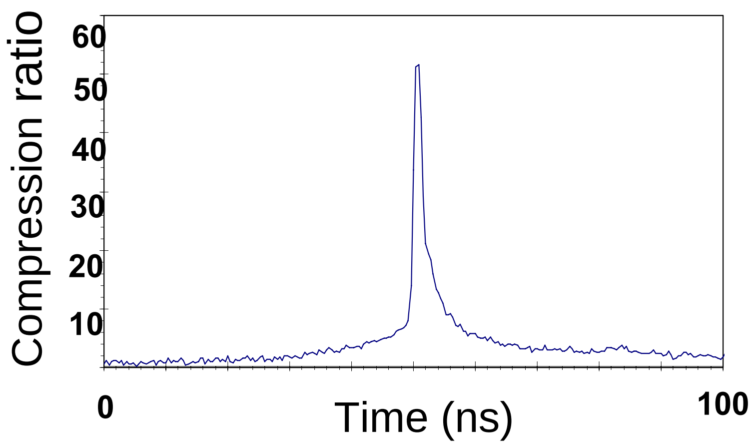
Beam diagnostics:

- beam size, fast Faraday cup
- energy analyzer (energy loss, charge state)

Target diagnostics:

- Stopping power
- Visible light emission (fast optical pyrometer)
- Laser, VISAR probes
- Streak camera
- Electrical conductivity





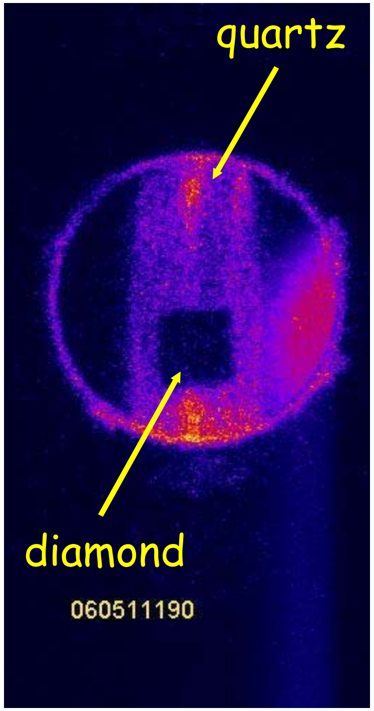
Compressed NDCX beam pulse

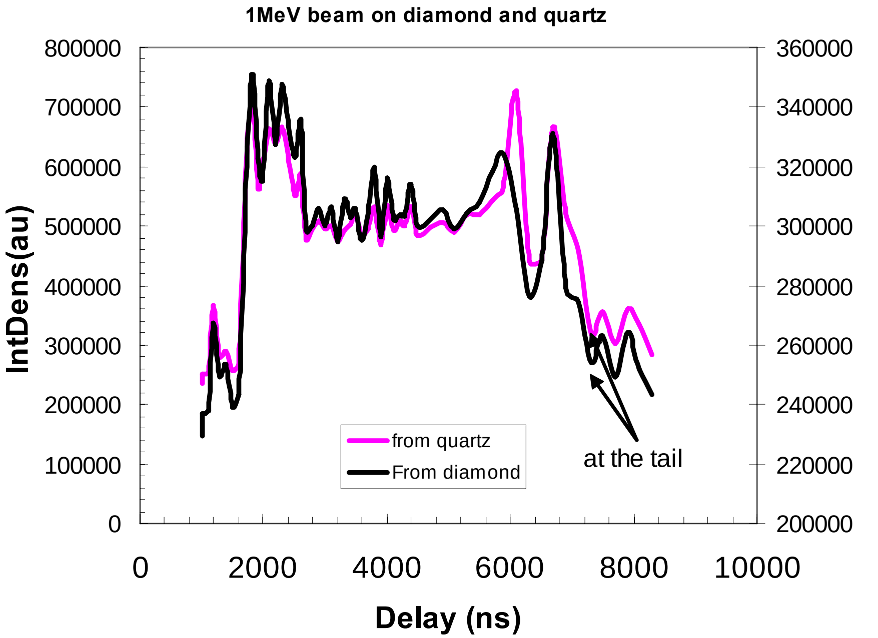
Limitations and issues with respect to prototype target chamber:

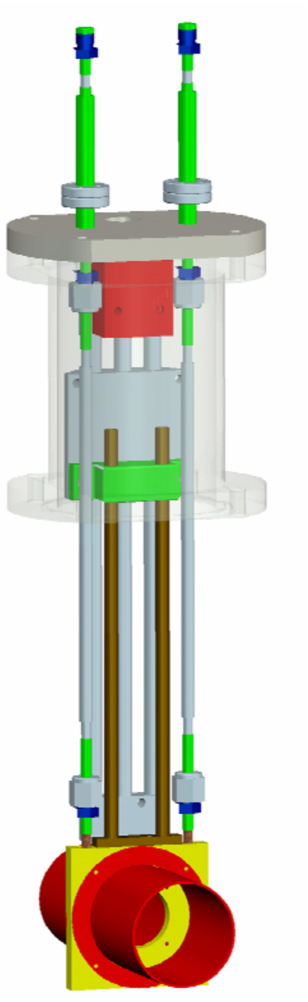
- **Load lock system required to load additional target modules**
- **Diagnostic access**
- **Compatibility with diagnostics, target manipulator**
- **Effect of target debris on chamber components**

- **Issues to explore with prototype chamber:**
  - **Electrical circuit and connections using target module**
  - **Motion issues with target manipulator. How to pick up target module from target rack and how to position it.**
  - **Refine module design**
  - **Interface with beam and target diagnostics**
  - **Influence of pulsed magnet and plasma source**

Initial measurements on HCX of optical emission, optical absorption for transient darkening experiment.







Optical emission: image and time response in liquid nitrogen cooled target

Plans for WDM experiments at HIFS-VNL

	Target temp.	NDCX-1 or HCX	NDCX-2
Transient darkening emission and absorption experiment to investigate previous observations in the WDM regime	**Low (0-0.4 eV)**	√	
Measure target temperature using a beam compressed both radially and longitudinally.	**Low**	√	
Thin target dE/dx, energy distribution, charge state, scattering.	**Low**	√	
Positive - negative ion plasma experiment.	**>0.4 eV**	√	√
Two-phase liquid-vapor metal experiments	**0.5-1.0**	√	√
Ion-driven Rayleigh-Taylor instability experiments	**0.5-1.0**		√
Critical point measurements	**>1.0**		√

time

Experiment at GSI (with D. Varentsov and GSI Plasma Physics group; IPCP Chernogolovka) to study porous targets.

- Motivation:
  - Porous media are of great interest to HEDP/WDM and have important practical applications.
  - Short range of low-energy beams forces short pulse (1 ns) and fast diagnostics – low density porous targets reduce need for very fast pulse by increasing hydro expansion time of target.

- Modeling support effort connects experimental measurements to physics of porous target – e.g. HYDRA code (LLNL; 1, 2, 3-D hydrodynamics); other codes under development (e.g. DPC; 1-D Lagrangian hydrodynamics; liquid-vapor EOS region).

2-3. Develop diagnostic techniques in parallel with improving beam capability.

- Thin foil target interaction experiments can be done using NDCX beam compressed longitudinally and transversely.
  - Collect transmitted beam downstream of target in a Faraday cup
  - Use energy analyzer, time-of-flight to measure energy distribution
  - Use scintillator to measure beam scattering in foil

Significance: ion scattering near Bragg peak of potential interest.

C. Deutsch, G. Maynard. Low velocity ion stopping of relevance to the US beam-target program, Hirschegg Workshop, Jan. 2006

M. Murillo, et.al., Determining dE/dx in warm dense matter using nonequilibrium molecular dynamics, WDM Workshop, Pleasanton, Feb. 2006

4. As target temperatures reach T=0.4 eV or higher, new WDM regimes become accessible.

- Positive-negative ion halogen experiment (T > 0.4 eV) [see L.R. Grisham, et.al., HIF 2006 Symposium]
  - This experiment explores the expected unique properties of a dense electron-free positive-negative ion halogen plasma
  - Diagnostics include beam energy loss, target temperature, etc.
  - Electronegativity of gold: 2.54 eV, is close to halogens: 3.98 (fluorine) to 2.66 eV (bromine) ➔ initial experiments may use gold foils

Significance: novel state of matter, unusual conductivity properties

- Target temperatures surpassing 1 eV open up further WDM regimes
  - Liquid-vapor transition
  - Droplet formation
  - Metal-nonmetal transition
  - Critical point measurements